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The Role of Chemical Engineering in Iligan City's Solid Waste Management Program

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Chemical engineering uses science and mathematics to evaluate and find solutions to problems related to food processing, materials development, environmental remediation and other challenges for the improvement of life. In this paper, knowledge on chemical engineering researches and principles are used to evaluate the proposed solid waste management project for Iligan City. Iligan City is situated in Northern Mindanao, about 800 km southeast of Manila, Philippines. It has a population of 322,821 persons as of May 2010, generating an average of 165 t of garbage per day. In 2005, the City Government applied for a loan amounting to USD 3.8 M for the construction of the Central Material Recovery and Composting Facility (CMRCF) to process the garbage. After eight years of construction and implementation, the project was stopped due to poor design, information and educational campaign failure, and misappropriation of resources. The City Council then requested the assistance of chemical engineers at Mindanao State University Iligan Institute of Technology (MSU-IIT). Studies at the chemical engineering laboratories of MSU-IIT were geared toward examining new alternative technologies to handle the mixed wastes. This paper presents technologies for the production of synthetic petroleum products from plastics, biomass gasification for electricity generation, and accelerated composting of kitchen and garden wastes using a patented composter and dehydrator machine. Research results are presented in graphs and tables; statistical tools are used to correlate empirical and experimental data. The research results served as sound basis in the evaluation and decision-making process on a company (Vistagreen Corporation) that claims to have clean technology for handling solid wastes, water-free waste processing, and waste-to-energy technologies based on thermolysis gasification followed by high temperature decomposition of toxic and residual wastes.

1. Central Material Recovery and Composting Facility (CMRCF) project status

The infrastructure development is composed of site development, access road development, and the construction of the following buildings: material recovery and composting facility, special waste and hazardous facility, administration building, warehouses, guardhouse, motor pool, and agriculture-demonstration farm. The closure and rehabilitation of the existing dumpsite is part of the infra development.
The project also includes the purchase and installation of the following equipment: receiving hoppers, parallel conveyor, cut-off conveyor, conveyor leading to trommel screener, trommel screener, plastic blower equipment, 4-way sorting mechanical conveyor, outfeed extension conveyor, screw conveyor for carbon amendment, loading conveyor, hammer mill/shredder/decorticator, hammer mill off-loading mechanical conveyor, steel trolleys, and portable power sprayer. The composting system and support equipment includes the following: 27 units of 2,000 L capacity rotary composter drum, steel ladder to composter drum, compost buggy, rotary screener, and bagging equipment. A mechanical baling or compaction machine is also included. Figure 1 shows three sets of solid waste sorting equipment and rotary bioreactors at the CMRCF. The total value for the equipment and installation is USD 645,293.00 (Villarin Quijano, 2014).
The facility is just for the mechanical sorting of the mixed wastes from the city. Although provisions for composting have been included, the effectiveness of the compost machines are in question, coupled with the difficulty of the operation. The facility also features vault storage for hazardous wastes. However, there are no provisions as to the final destination and treatment of the wastes. From the concept of material balance and

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accumulations, the facility would eventually stop its operations because of the volume build-up of untreated waste. Sound chemical engineering advice should have been sought prior to the approval of the project.

(a) Conveyor leading to trammel conveyor

(b) 4-way sorting mechanical conveyor

(c) Rotary composter drums

Figure 1: Sets of solid waste sorting equipment and rotary bioreactors at the CMRCF

2. Research studies at MSU–IIT

At the Department of Chemical Engineering and Technology of the College of Engineering, MSU–Iligan Institute of Technology, researches are geared toward the treatment of mixed wastes from the city. These studies are as discussed in the following sub-sections.

2.1 Accelerated composting of biomass

The application of inorganic fertilizers provides the major nutrients needed by the plants. However, according to Jeyathilake (2006), its excessive use can lead to soil infertility and damage to the environment. Fertilizer from organic wastes reduces negative environmental effects and tends to restore soil fertility. This study was conducted to produce a compost using the Convertible Composter and Dehydrator Machine (Philippine Patent Application No.: 12015000098) and to evaluate its impact on the growth and yield of tomatoes. Commercial (inorganic) fertilizer was also used alone and in combination with the compost according to the treatment protocol based on the work of Koenig et al. (2011).

The experiment consisted of five treatments and was laid in Randomised Complete Block Design (RCBD) with fifteen replications. Data collected from compost analysis showed minimum levels of macronutrients (NPK) and a high level of organic matter (OM). The production indicator showed that the tomatoes were significantly affected ($p < 0.05$) by different compost to commercial fertilizer ratio (Naika et al., 2005). Plant health due to climatic conditions, fruit sizes, weight and number per plant, and the total yield per hectare are studied. Table 1 gives the initial conditions of the study. Table 2 shows that tomato plants treated with the combination of 50 % compost and 50 % commercial fertilizer produced a higher yield and quality of tomato.

Table 1: Summary of chemical properties of soil, inorganic fertilizer, and compost

Parameter	Soil	Inorganic fertilizer	Compost
Organic C (g/kg)	8.890	-	240.500
Total N (g/kg)	0.445	140	6.000
Available P (g/kg)	0.029	140	0.036
Total K (g/kg)	0.510	140	13.970
Organic matter (g/kg)	15.300	-	481.000
pH	7.460	-	7.790

Table 2: Average tomato fruit size and weight for each treatment

Treatment	Fruit equatorial diameter (mm)	Fruit longitudinal diameter (mm)	Average fruit weight (g)	Total yield per hectare (kg)
T (1)	33.80^{b}	42.48^{b}	25.19^{c}	729.29
T (2)	42.41^{a}	47.41^{a}	44.79^{ab}	2,059.94
T (3)	42.94^{a}	49.78^{a}	45.58^{a}	1,918.55
T (4)	41.89^{a}	47.51^{a}	43.11^{ab}	2,244.99
T (5)	41.49^{a}	47.75^{a}	42.36^{b}	1,958.40

Different letters indicate significant differences between treatments according to Tukey test ($p < 0.05$): T(1) – control; T(2) – pure inorganic fertilizer; T(3) – pure compost; T(4) – 50 % inorganic, 50 % compost; and T(5) – 25 % inorganic, 75 % compost.

2.2 Plastics to synthetic petroleum products

Another study was focused on the conversion of plastics to synthetic fuels. This study aims to convert waste thermoplastics into alternative fuel oil (Cleetus et al., 2013). Through pyrolysis, a thermochemical technique used to decompose materials at high temperatures and in the absence of air, these long hydrocarbon chains are broken down into shorter chains in the form of volatile gases (Singh et al., 2010). Catalytic and thermal degradation of waste thermoplastics was studied in a simple pyrolysis reactor system. The three types of plastics used as raw materials were the following: Low Density Polyethylene (LDPE), Polypropylene (PP), and Polystyrene (PS). Four feed stocks, one for each type of plastic and proportional mixture of LDPE-PP-PS, were also used. The liquid fuel oil yield at reaction temperatures between 400 °C to 500 °C for each type of plastic were characterised (Panda et al., 2015). Alumina was the catalyst used at 10 : 1 plastic-to-catalyst ratio. A Shimadzu 60-H TGA / DTG Analyser was used to determine the burning characteristics of the plastics as shown in Figure 2. A PARR 1281 bomb calorimeter was used to determine the gross calorific values of the liquid fuel oils found to be in the range of 41.64 kJ/g to 45.89 kJ/g as shown in Table 3. Results of pyrolysis experiments for LDPE and PP showed that the condensable fraction obtained at low temperature had low viscosity but was highly volatile. Above 450 °C, the condensates turned into a waxy material. PP yields the most volume of fuel oil. LDPE-PP-PS mixture yields a maximum of 88 % at 500 °C. The liquid fractions obtained were analysed for functional groups as shown in Figure 3 for PP using Fourier Transform Infrared Spectroscopy. With this technology, environmental problems regarding waste plastics as well as the foreign oil dependency can be minimised.

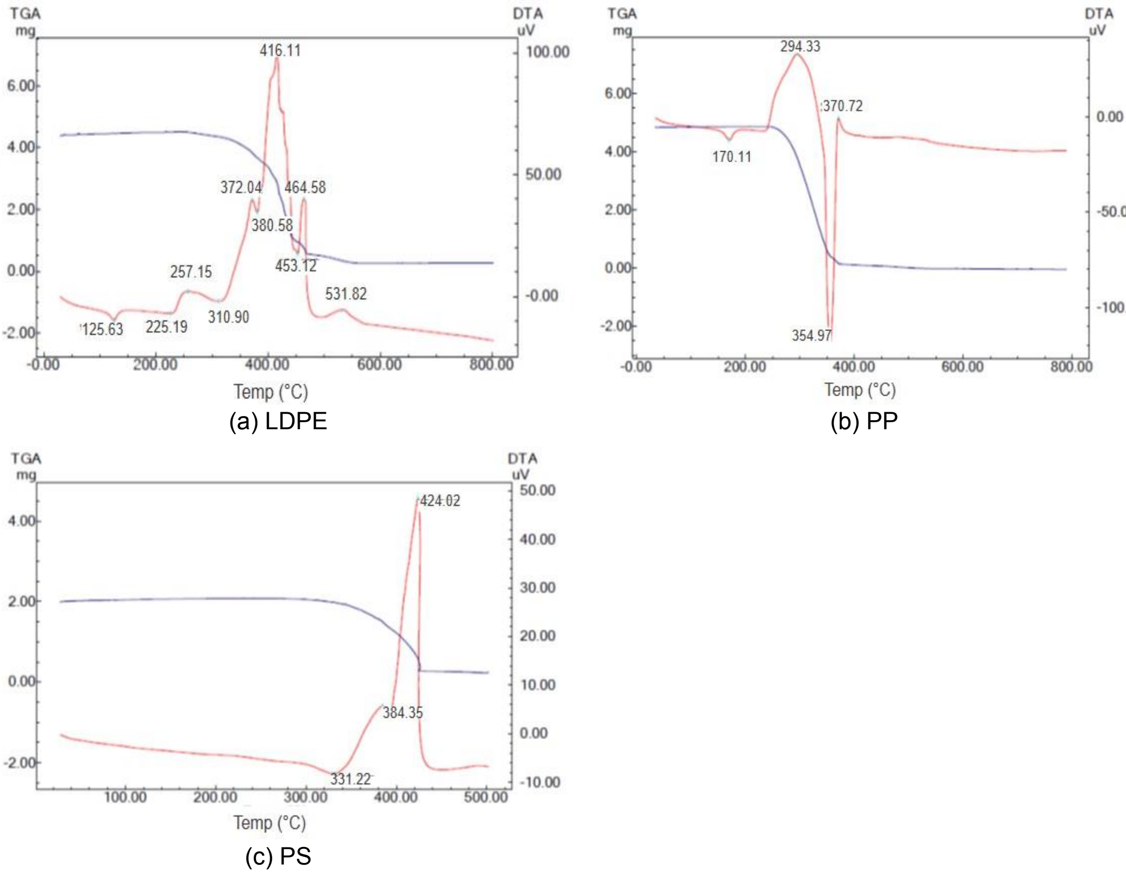

Figure 2: TGA/DTA analysis of (a) LDPE, (b) PP, and (c) PS

Table 3: Average specific gravity and calorific values of synthetic fuels

Type of plastic	Colour	Yield (%)	Specific gravity	Gross calorific values (kJ/g)
LDPE	Yellow	67.50	0.768	45.78
PP	Dark yellow	82.66	0.767	45.89
PS	Brown	75.00	0.912	41.64
Mixed	Black	77.66	0.824	43.46

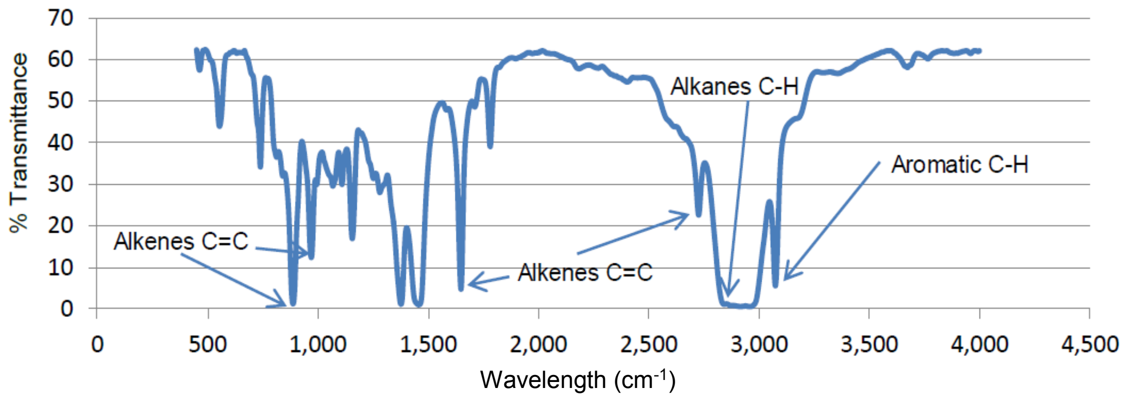

Figure 3: FTIR graph for PP fuel oil showing alkenes, alkanes and aromatic C-H bonds

2.3 Gasification of biomass

The energy contained in a coconut shell needs to be transformed to heat and chemical energy before it can be utilized (Barrio, 2002). A small-scale updraft gasifier, as shown in Figure 4, served as the test rig with coconut shell charcoal as a feedstock and air as the oxidising agent. A proximate and ultimate analysis was done on the shell following the correlation techniques by Parikh et al. (2007). Thermo-gravimetric analysis was performed using Shimadzu DTG 60H to investigate the thermal degradation of the biomass inside the reactor. Heating value of the biomass was determined using PARR 1281 oxygen-bomb calorimeter. Gasification temperature ranges from 400 °C to 900 °C using 25 kg of charcoal. To predict the composition of the product gas, thermodynamic equilibrium modelling approaches, as presented by Cagnon et al. (1992), were applied. Results of the model shows that the gases, comprising of H_2 (3.99 – 12.39 %) and CO (0.37 – 32.82 %), increased while that of CO_2 (20.53 – 0.31 %), H_2O (0.05 – 0.03 %), CH_4 (2.61 – 0.03 %), and N_2 (72.44 – 54.3 %) decreased as the gasification temperature was increased. Higher H_2 and CO composition increases the heating value as shown in Table 4. The gas efficiency (28.57 – 76.57 %) increased as the reaction temperature increased. This study generates electricity from gasification of coconut shell charcoal as shown in Figure 4 confirming the study of Chhiti and Kemiha (2013) when they declared that producer gases can be a substitute of natural gas for heat and energy generation.

(a) Updraft gasifier

(b) Control valves with 3.5 kW generator

(c) Stable gas combustion

Figure 4: Updraft gasifier experimental setup

3. Vistagreen Technology

Vistagreen Corporation (VC) is a fully registered corporation in the Philippines (Gallarde, 2016). It is planning to invest, build, and operate waste-to-energy (WTE) gasification plants using technologies developed in Europe. The plant converts municipal solid wastes into energy using thermal treatments that allow for the intermediate transformation of any mixed waste into a synthetic gas consisting of CO and H_2 and synthetic diesel (Euro IV). The company claims that the synthesis gas and diesel can be a substitute to natural gas, oil, and other fossil fuels in steam boilers and gas turbines, as well as a substitute for liquid fuels in internal combustion engines.

Table 4: Table showing the producer gas composition, heating value, cold gas efficiency, and equivalent electricity generated from coconut shell charcoal at different temperatures

Run	Temp, °C	H_2, vol%	CO, vol%	CO_2, vol%	H_2O, vol%	CH_4, vol%	N_2, vol%	Air intake, kmol	Heating Value, MJ/m^3	CGE, %	Energy, kWh
1	400	3.990	0.370	20.53	0.05	2.61	72.44	0.73	1.50	28.57	2.52
2	525	6.970	4.050	17.92	0.24	0.74	70.07	0.73	1.64	32.47	2.87
3	650	9.520	17.27	9.730	0.31	0.24	62.93	0.54	3.47	57.60	5.09
4	775	11.78	29.93	2.050	0.12	0.09	56.04	0.41	5.33	75.29	6.65
5	900	12.39	32.82	0.310	0.03	0.03	54.43	0.39	5.75	78.66	6.94

Among other advantages, VC claims superiority over other incinerators, sustaining exothermic reactions by burning the synthesis gas in a specially designed afterburner to deliver the best environmental performance. The technology further claims that the energy conversion efficiency is high—that is, 95 % of the energy contained in wastes is transformed to synthesis gas as seen in Figure 5.

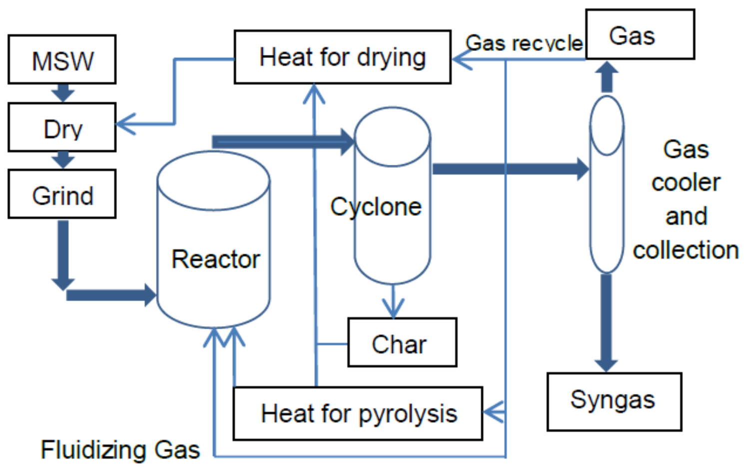

Figure 5: Schematic diagram of MSW gasification process as presented by Vistagreen Corporation

After a careful analysis of Vistagreen Corporation's proposal and from the results of the research activities at the MSU–Iligan Institute of Technology laboratories, the following were recommended to avoid the CMRCF failure:

1. VC shall use technologies that have emission levels in compliance of EU 2030 directives as well as compliant to the Republic Act (RA) No. 9003 known as the Ecological Solid Waste Management Act of 2000, RA No. 9275 known as the Philippine Clean Water Act of 2004, and RA No. 8749 known as the Philippine Clean Air Act of 1999. To comply with these laws, it is mandatory for VC to incorporate plasma gasification of toxic wastes, lime treatment of wash/wastewater, and mechanical solid-gas separation. These new and advanced technologies must become integral components of the treatment protocol to solve problems observed during the study on plastics to synthetic petroleum product conversion.

2. VC shall institute contingency measures within its designated facility to handle the continued delivery of MSW from the local government unit (LGU) during scheduled and unexpected downtimes of the waste-to-energy facility. VC shall ensure that solid products in the form of compost and dry ash must be delivered to pre-arranged users while synthetic petroleum fuel shall continuously be used or sold to industrial partners

for safety purposes. Accelerated biomass composting and biomass gasification as represented by coconut shell charcoal studies presented real situations that must be addressed by VC.

3. VC and LGU shall form a multipartite monitoring team (MMT) from the start of the design, construction, commissioning, and for the duration of the project life. The MMT shall perform the functions and provisions as stated in Department of Environment and Natural Resources Administrative Order No. 2003-30. This recommendation is based on readings conducted prior to waste to resource studies.

4. Conclusion

The construction of the Central Material Recovery and Composting Facility amounting USD 3.8 M would have been a success story with the active participation of chemical engineering professionals. Researches on accelerated biomass composting, biomass gasification and plastic to synthetic fuel conversions among others must become an integral part of project proposals related to environmental problems and remediation.
Clearly, prior knowledge attained by chemical engineers is a determinant factor in making long-term decisions for the protection and sustainability of our environment.

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